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Project Report: Origins of planetary systems

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Project Progress

How are planets born? In what type of environment, and under what conditions do most stars (and associated planetary systems) form? How do grains and gas in proto−planetary systems evolve from interstellar properties to solid bodies? I have been using the world's largest telescopes (such as the Keck 10m and Gemini 8m telescopes) to search for answers at wavelengths between 0.5 and 20 µm.

Most stars form in rich clusters that include massive stars where ultraviolet (UV) radiation and close passages of sibling stars pose hazards to proto−planetary disks. However, these hazards predominantly impact the outer parts of circumstellar environments; the inner 10 Astronomical Unit regions can survive for 10s of millions of years. Henry Throop (SWRI) and I are finding that UV radiation fields may actually stimulate planetesimal formation. While radiation and dynamical processes can rapidly strip away outer disks, exposure to UV may promote condensation of solid bodies in the planetary zone. UV preferentially removes light gases and small grains; large particles become concentrated in the disk mid−plane and can rapidly evolve toward gravitational instabilities.

Some aspects of planet formation and disk evolution require precision photometry with small telescopes. I started a program to monitor variations to select a sample of young stars with nearly edge−on disks whose gas and grain properties can be further probed by UV, visual, and near−infrared spectroscopy.

Highlights

- We have found evidence for proto−planetary disks in the Carina nebula similar to those in the Orion nebula. However, Carina has nearly 100 times the radiation field of Orion and is thus a much harsher environment for star and planet formation. We have been awarded Hubble Space Telescope and Spitzer Space Telescope time to follow up our preliminary work with ground−based telescopes.

- We used the Gemini−South 8m telescope to obtain thermal infrared images, sensitive to the presence of 100 to 500 Kelvin dust, of young stars embedded in the Orion nebula. These data show that most of Orion's "naked" young stars – those NOT showing evidence for large disks or "proplyds" traits in Hubble Space Telescope images – are surrounded by warm dust, presumably in a compact circumstellar disk in the planet−forming zone.
- We used high−resolution spectroscopy of atomic hydrogen lines emitted by Orion's "naked" stars to confirm the existence of compact inner disks. The Apache Point Observatory 3.5 m spectra, and our Fabry−Perot data cubes show emission features consistent with Keplerian disks directly illuminated by ionizing radiation from Orion's massive stars. The emitting gas appears to be bound by gravity to the circumstellar disk.
- To explore disk survival in intense UV radiation fields, I generated an analytic model for the evolution of a highly idealized disk. This model confirms that disk mass loss declines as a strong function of disk outer radius. The inner−planet−forming portions of disks can outlive the massive stars providing external illumination.
- Henry Throop (South West Research Institute) and I have found that UV radiation can actually enhance the onset of gravitational instabilities in disks, leading to "triggered" planetesimal formation. We are developing a numerical model based on Henry's PhD thesis to study the combined effects of UV−induced photo−ablation, grain growth, sedimentation of large particles towards the disk mid−plane, radial drift of these particles due to the "headwind" of thermally supported gas, accumulation of large particles near gaps, and the onset of self−gravitational condensation into planetesimals.
- A new initiative uses a network of small telescopes to continuously monitor the light variations of young stars to find rare objects in which our line−of−sight skims along the disk surface. One goal of this program is to select objects for further study at UV wavelengths (to measure composition and grain properties) before the Hubble Space Telescope dies, effectively preventing such measurements for a decade or more. Additional goals are accurate calibration of large−telescope data, the search for protostellar eruptions and flares associated with accretion, and identification of complete samples of young stars in selected regions. A commercial CCD camera, a computer controlled mounting, and an existing C−14 telescope are being used for this study. The camera, mounting, and software are identical to the 16−inch "VYSOS" telescopes being deployed by my collaborators Bo Reipurth and Rolf Chini for sites in Hawaii and Chile.

Roadmap Objectives

- ***Objective No. 1.1:*** Models of formation and evolution of habitable planets